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HYBRID-FUZZY GRID CONNECTED PV/PEMFC/BATTERY DISTRIBUTED GENERATION SYSTEM

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Abstract - *In today's distribution grids the number of distributed generation (DG) units is increasing rapidly. This paper describes the power control strategies of a fuzzy controlled grid connected hybrid photovoltaic and fuel cell distributed generation system with battery as energy storage device. The primary source of energy for the hybrid distributed generation system is from photovoltaic cell, fuel cell and the battery acts as a complementary source of energy. The hybrid distributed generation system is connected to a grid through power electronic interfacing devices. A Matlab/Simulink model is developed for the grid connected hybrid distributed generation system and fuzzy controlled power electronic DC/DC, DC/AC converters to control the flow of power on both sides. Hybrid fuzzy model is also developed for this paper. Simulation results illustrate the performance of the hybrid system following the load demand and operating the system with fuzzy and hybrid fuzzy controller.*

Keywords - *PV cell, Fuel Cell, Battery, Distributed Generation, MPPT, Fuzzy Control, Hybrid Fuzzy Control*.

I .INTRODUCTION

Today, new advances in technology and new directions in electricity regulation encourage a significant increase of distributed generation resources around the world. The current electricity infrastructure in most countries consists of bulk centrally located power plants connected to highly meshed transmission networks. However, a new trend is developing toward distributed energy generation, which means that power conversion systems will be situated close to energy consumers and the few large units will be substituted by many smaller ones. One of the prevalent alternative sources of electric power is the fuel cell (FC).

Fuel cells have attracted much attention as an efficient, scalable, low-pollution means of generating electrical power. However, limited by their inherent characteristics, such as a long start-up time and poor response to instantaneous power demands, hybrid fuel cell/battery power generation systems have been presented to reach the high power density of batteries with the high energy density of fuel cells. Solar (photovoltaic, PV) energy is a major renewable energy source at the forefront of standalone and distributed power systems.

PV power systems are however dependent on climatic conditions and their output depends on the time of year, time of day, and the amount of clouds. Hybridization of fuel cell with PV will therefore form a very reliable distributed generation where the fuel cell acts as back up during low PV output. The slow dynamics of the fuel cell can be compensated by adding battery energy storage. If a fuel cell was connected to a step increase in load, it would provide the current, but the voltage could instantaneously drop off the V-I curve and the fuel cell would take several seconds until it begins feeding the required power. In the mean time, the fuel cell may be starved of fuel which is not good for the electro catalyst shortening its life.

In this paper proton exchange membrane fuel cell was used. MPPT is a technique used commonly with wind turbines and photovoltaic (PV) solar systems to maximize power extraction under all conditions. Although solar power is mainly covered, the principle applies generally to sources with variable power.

Solar cells have a complex relationship between temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve. In this paper MPPT was controlled by using fuzzy control and hybrid-fuzzy control. To reduce the disturbance in dc output voltage hybrid-fuzzy control is used. The hybrid system is connected to load and grid through dc/ac converter. Dc/ac converter is controlled by using fuzzy logic controller.

II. SYSTEM STRUCTURE

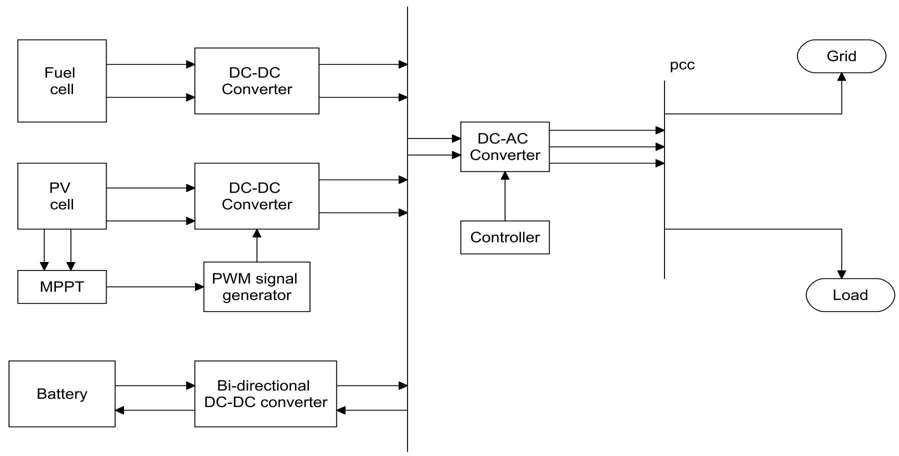

Fig 1: Basic Block Diagram of Grid Connected Hybrid System

The above Fig 1 shows that basic block diagram of grid connected hybrid system. It consists of PV/PEMFC/BATTERY hybrid source with grid connected. Here fuel cell and PV cell are primary sources and battery is used as complementary source of energy

1) ***Fuel Cell:***

A fuel cell is an electrochemical cell that converts the chemical energy from a fuel into electricity through an electrochemical reaction of hydrogen fuel with oxygen or another oxidizing agent. They show great promise to be an important DG source of the future due to their many advantages, such as high efficiency, zero or low emission (of pollutant gases), and flexible modular structure. Fuel cells are different from batteries in requiring a continuous source of fuel and oxygen (usually from air) to sustain the chemical reaction, whereas in a battery the chemical energy comes from chemicals already present in the battery. Fuel cells can produce electricity continuously for as long as fuel and oxygen are supplied.

There are many types of fuel cells, but they all consist of an anode, a cathode and an electrolyte that allows positively charged hydrogen ions (protons) to move between the two sides of the fuel cell.

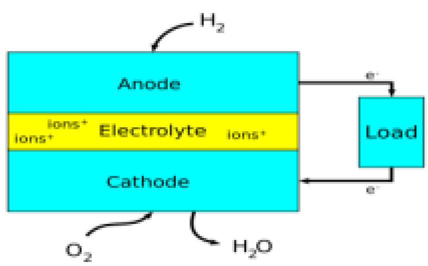

Fig 2: Fuel cell connected to load

In this proton exchange membrane fuel cell was used. The electrolyte for this fuel cell is polymer membrane (ionomer).The qualified power is in the range of 1w-500kw. Efficiency of this cell is 50%-70%. PEM fuel cells operate at relatively low temperatures, around 80°C (176°F). Low-temperature operation allows them to start quickly. The fuel cell stack is connected to dc-dc boost converter to boost up the voltage based on load utility. At certain conditions, dc output voltage from fuel cell was not met the load demand. At that case, dc-dc boost converter will work.

2) **Photovoltaic Cell:**

A photovoltaic cell (PV cell) is a specialized semiconductor diode that converts visible light into direct current (DC). Some PV cells can also convert infrared (IR) or ultraviolet (UV) radiation into DC electricity. Photovoltaic cells are an integral part of solar-electric energy systems, which are becoming increasingly important as alternative sources of utility power. The following shows that equivalent circuit model.

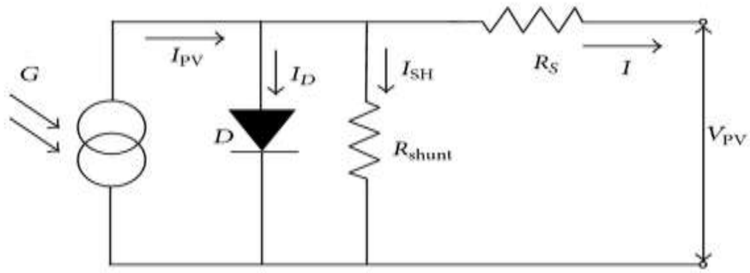

Fig 3: The equivalent solar cell model with Rs and Rsh

G – Solar irradiance ,D – Diode, Rsh – Shunt resistance, Rs – Series resistance, Vph – PVcell voltage, Iph – PVcell current, Id – Diode current, Ish – Current in Shunt resistance, Is – Current in series resistance.

Solar PV has specific advantages as an energy source: once installed, its operation generates no pollution and no greenhouse gas emissions. It shows simple scalability in respect of power needs and silicon has large availability in the Earth's crust. PV systems have the major disadvantage that the power output is dependent on direct sunlight, so about 10-25% is lost if a tracking system is not used, since the cell will not be directly facing the sun at all times. Dust, clouds, and other things in the atmosphere also diminish the power output. Due to these disadvantages maximum power point tracking is used. In this MPPT, there are many techniques available. Here, to track maximum power fuzzy mppt control was used. The output from mppt control was given to dc-dc converter through pulse width modulation. The pwm controls the duty ratio of GTO switch in dc-dc boost converter.

3) **Battery Modeling:**

Batteries convert chemical energy directly to electrical energy. A battery consists of some number of voltaic cells. Each cell consists of two half-cells connected in series by a conductive electrolyte containing *anions* and cations. One half-cell includes electrolyte and the negative electrode, the electrode to which anions (negatively charged ions) migrate; the other half-cell includes electrolyte and the positive electrode to which cations (positively charged ions) migrate. Redox reactions power the battery. Cations are reduced (electrons are added) at the cathode during charging, while anions are oxidized (electrons are removed) at the anode during charging. During discharge, the process is reversed. The electrodes do not touch each other, but are electrically connected by the electrolyte. Some cells use different electrolytes for each half-cell. A separator allows ions to flow between half-cells, but prevents mixing of the electrolytes. The following fig shows the battery model based on voltage model.

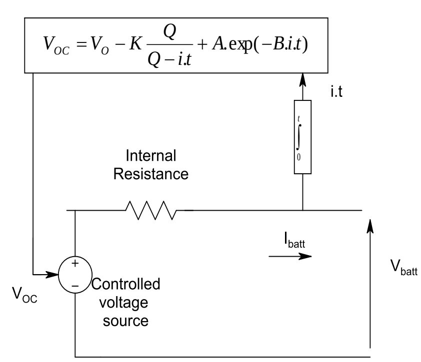

Fig 4: Battery Model

Here is used as complementary source. Battery model is connected to bi-directional dc-dc converter. Whenever the supply doesn't meet the load demand. Battery will supply power to the load. Whenever the supply is more than the utility ,at that condition battery will stores the energy.

4) Dc-Dc Boost Converter:

Power for the boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost converter is a DC to DC converter with an output voltage greater than the source voltage. A boost converter is sometimes called a step-up converter since it "steps up" the source voltage. Since power (P=VI)must be conserved, the output current is lower than the source current. The following fig shows the dc-dc converter model.

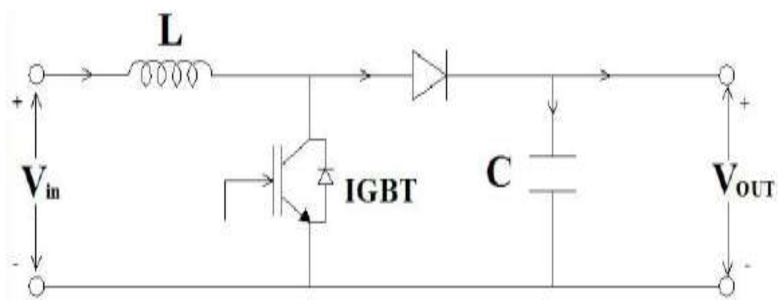

Fig 5 : Dc-Dc boost converter model.

The Dc-Dc boost converter model consists of one switching device IGBT. It will turn and turn off based on gate signal D provided. The gate signal D will be given by fuzzy controller.

5) Dc/Ac Inverter Model :

The outputs coming from all the sources are in dc. In order to convert the output of dc into ac, Dc/Ac inverter model was used.

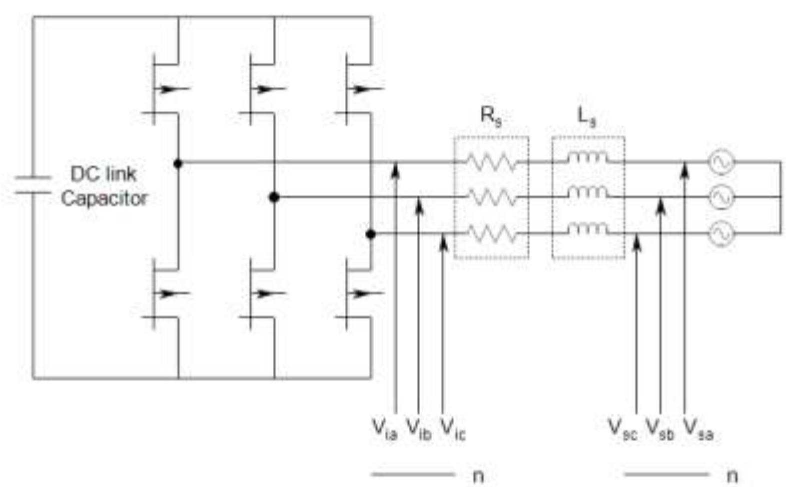

Fig 6: Dc/Ac three phase inverter

A power inverter, or inverter, is an electronic device or circuitry that changes direct current (DC) to alternating current (AC).The input voltage, output voltage and frequency, and overall power handling depend on the design of the specific device or circuitry. The inverter does not produce any power, the power is provided by the DC source. The dynamic model of the voltage source inverter (VSI) is used. The VSI will be controlled by sing fuzzy controller.

III. FUZZY CONTROLLER

A fuzzy control system is a control system based on fuzzy logic a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0. The input variables in a fuzzy control system are in general mapped by sets of membership functions similar to this, known as "fuzzy sets". The process of converting a crisp input value to a fuzzy value is called "fuzzification". The membership functions are with seven linguistic variables sush as, negative big, negative medium, negative small, zero, positive small, positive medium, positive big. Fuzzy control is based on rules. In inference engine fuzzy sets will be taken as input and knowledge based rules are written. In this mamdani method is used. It consists of 49 rules in the form if/then.

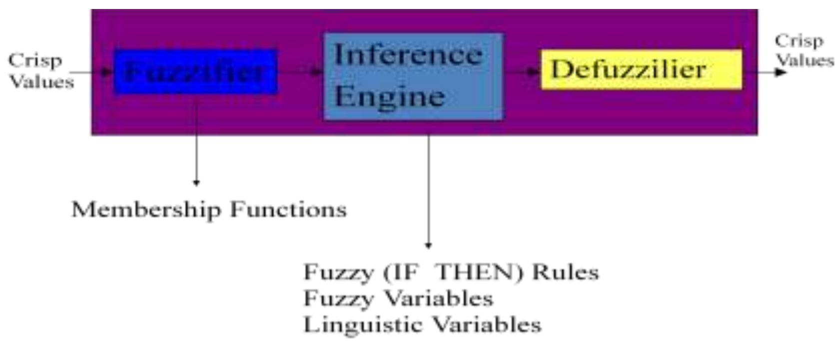

Fig 7: Basic fuzzy control diagram

The above fig shows the basic fuzzy control diagram. Using these 49 rules based on membership function, fuzzy control will be done. After that defuzzification process will be carried. Fuzzy sets into data sets. By using input and output membership functions and rules, the error in voltage will be modified. In this paper, fuzzy control was used in MPPT, Dc-Dc boost converter and Dc/Ac inverter. This fuzzy control is knowledge based

IV. HYBRID FUZZY CONTROL

Hybrid fuzzy control is the most effective control compared to fuzzy control. The objective of the hybrid controller is to utilize the best attributes of the PI and fuzzy logic controllers to provide a controller which will produce better response than either the PI or the fuzzy controller. There are two major differences between the tracking ability of the conventional PI controller and the fuzzy logic controller. Both the PI and fuzzy controller produce reasonably good tracking for steady-state or slowly varying operating conditions.

However, when there is a step change in any of the operating conditions, such as may occur in the set point or load, the PI controller tends to exhibit some overshoot or oscillations. The fuzzy controller reduces both the overshoot and extent of oscillations under the same operating conditions. Although the fuzzy controller has a slower response by itself, it reduces both the overshoot and extent of oscillations under the same operating conditions. The desire is that, by combining the two controllers, one can get the quick response of the PI controller while eliminating the overshoot possibly associated with it. Switching Control Strategy the switching between the two controllers needs a reliable basis for determining which controller would be more effective. The following shows that basic block diagrammatic representation of hybrid fuzzy control

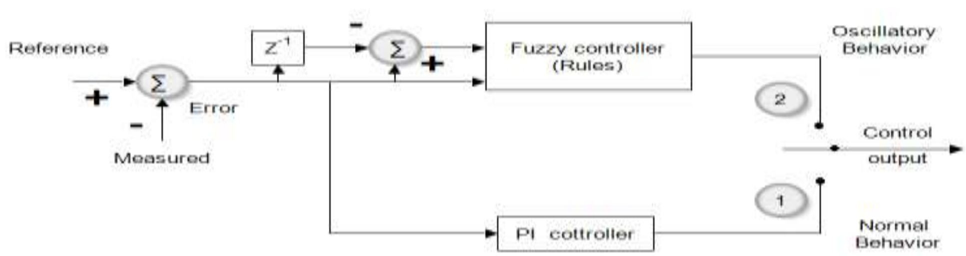

Fig 8: basic diagram of hybrid fuzzy controller

The answer could be derived by looking at the advantages of each controller. Both controllers yield good responses to steady-state or slowly changing conditions. To take advantage of the rapid response of the PI controller, one needs to keep the system responding under the PI controller for a majority of the time, and use the fuzzy controller only when the system behavior is oscillatory or tends to overshoot. Thus, after designing the best stand-alone PI and fuzzy controllers, one needs to develop a mechanism for switching from the PI to the fuzzy controllers, based on the following two conditions:

- Switch when oscillations are detected;
- Switch when overshoot is detected.

Here hybrid fuzzy control was used in MPPT control. To get the better dc output voltage whenever any changes occurred .compared to fuzzy control it has best response in terms of steady-state and peak overshoot. Simulation results illustrate these performances.

V. MATLAB/SIMULINK MODEL

The proposed concept of this paper is developed in matlab. The following figure shows the matlab/simulink model

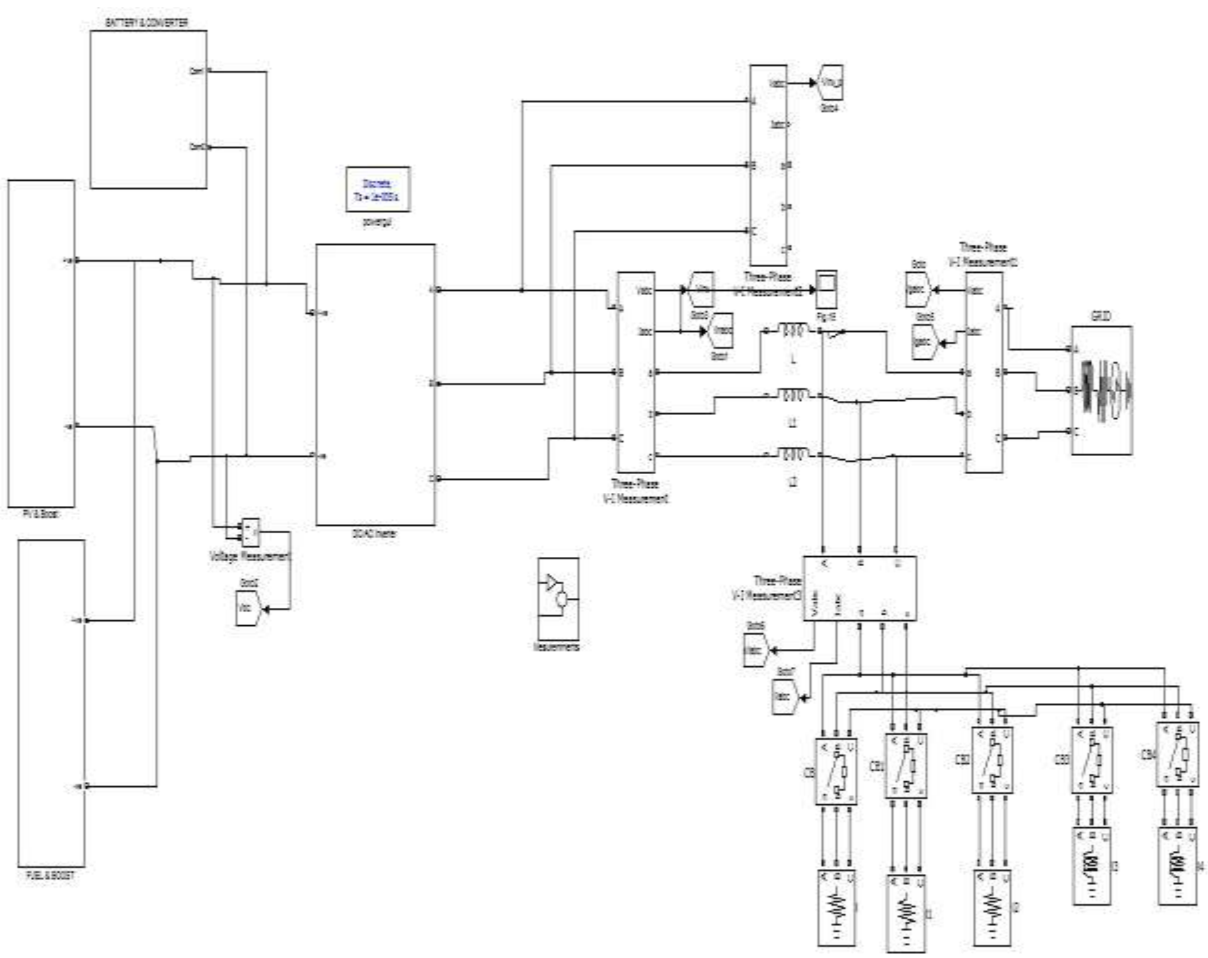

Fig 9: matlab/simulink model of fuzzy and hybrid fuzzy controlled gird connected hybrid pv/pemfc/battery distributed generation system.

VI. MATLAB/SIMULINK RESULTS

The performances for proposed concept results was carried out and shown below

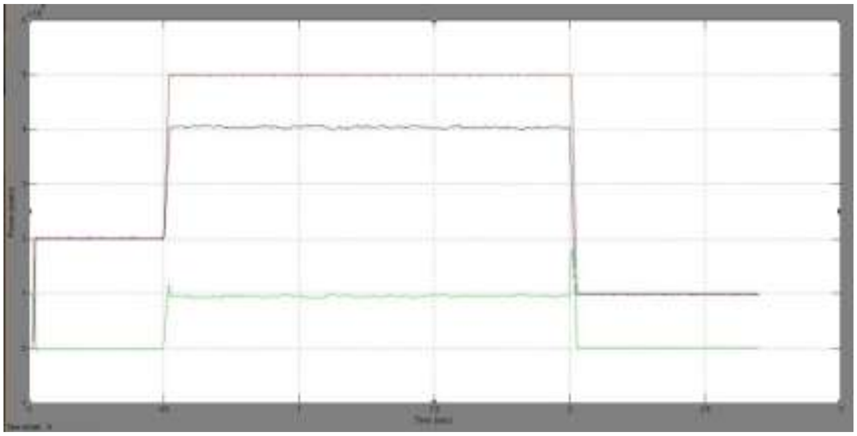

Fig10: simulation results of active,hybrid & grid power

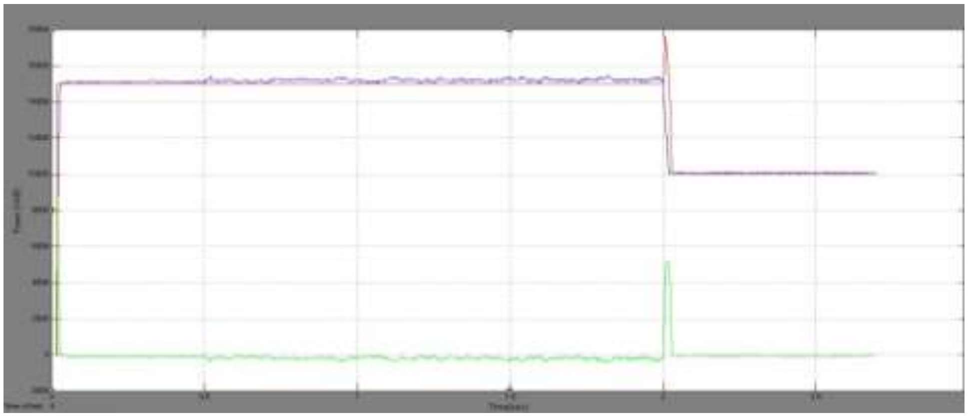

Fig 11: simulation results of reactive load, hybrid power system & grid power

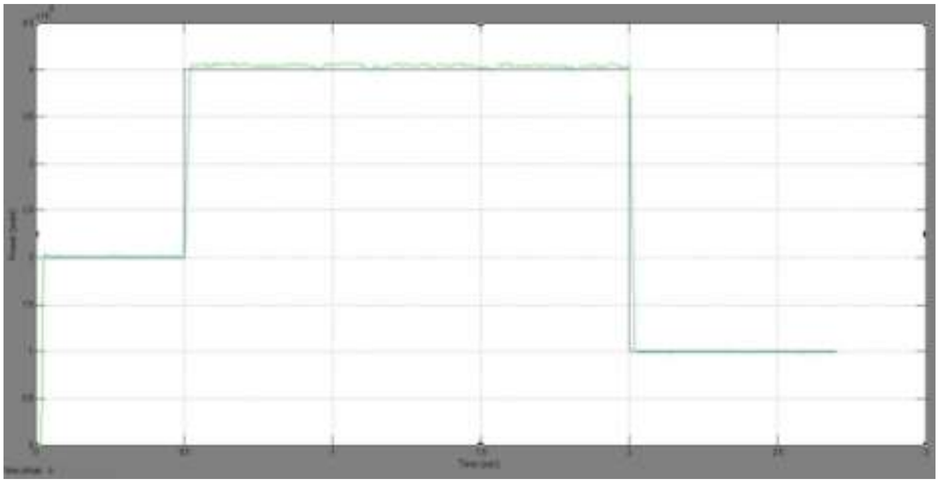

Fig 12: simulation results of hybrid active power & reference active power

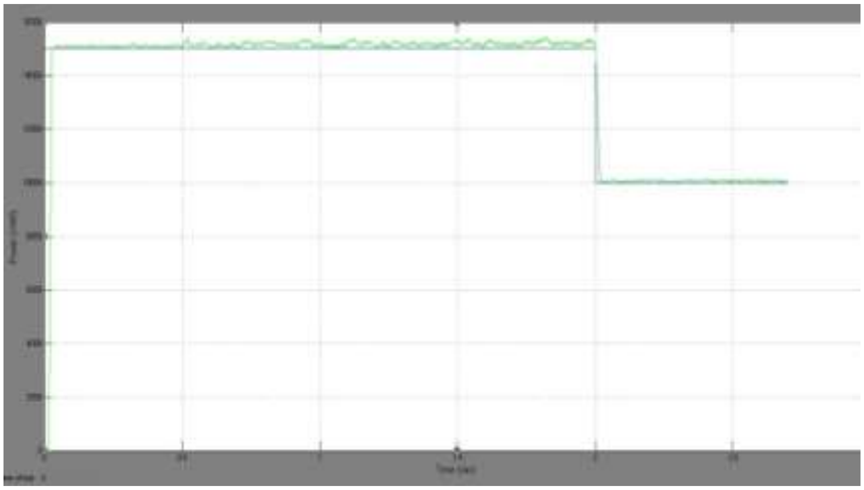

Fig 13:simulation results of hybrid reactive power & reference reactive power

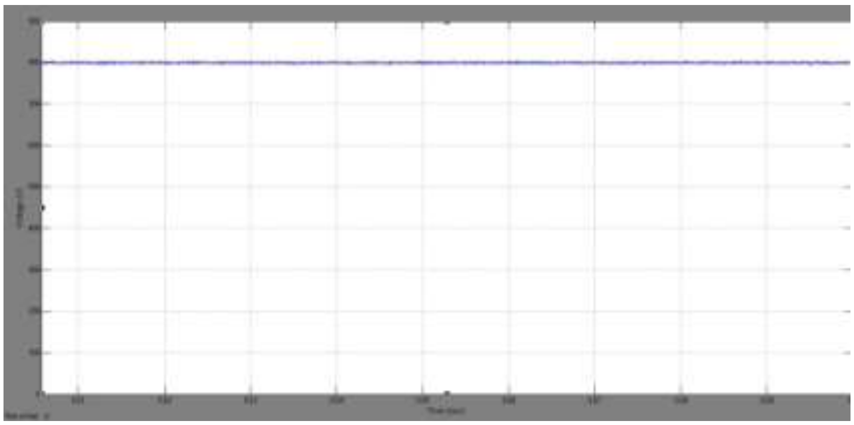

Fig 14: simulation results of battery voltage

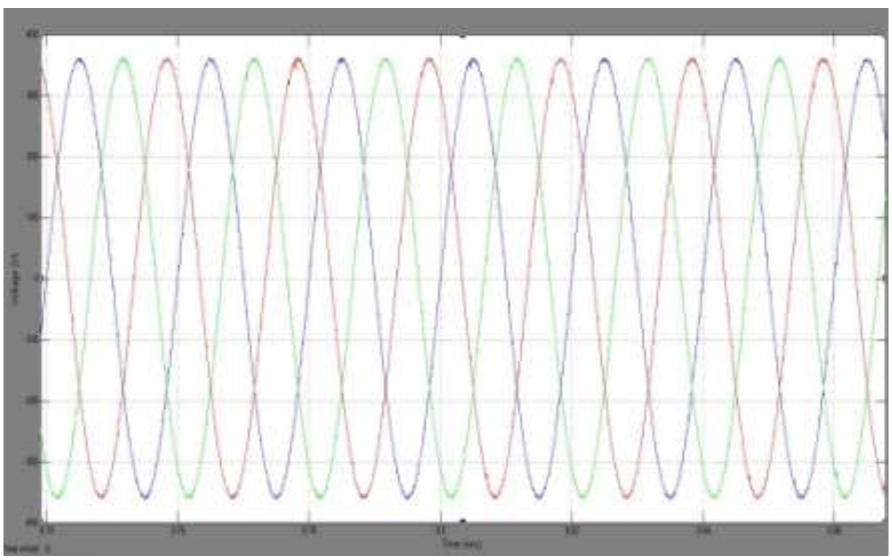

Fig 15: simulation results of voltage at pcc

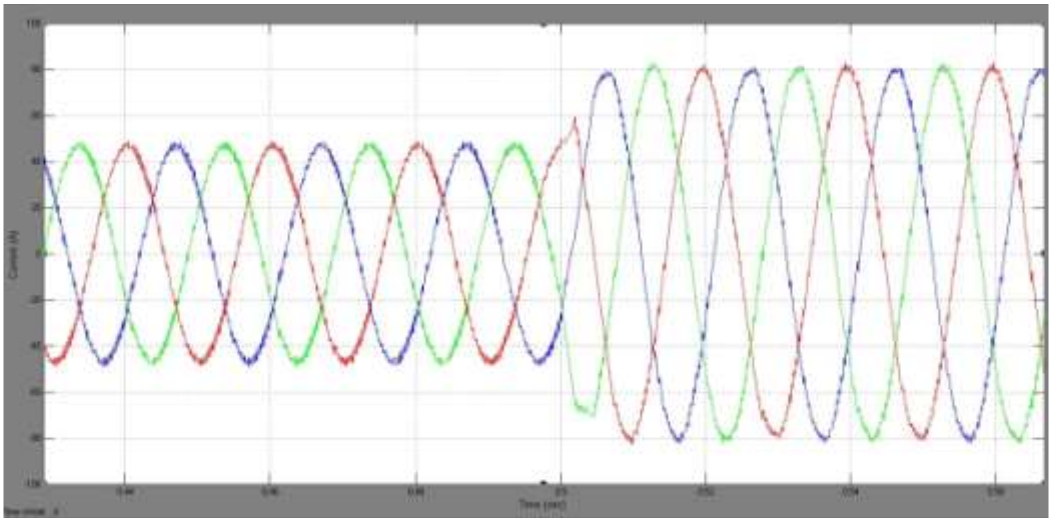

Fig 16: simulation results of currents at pcc

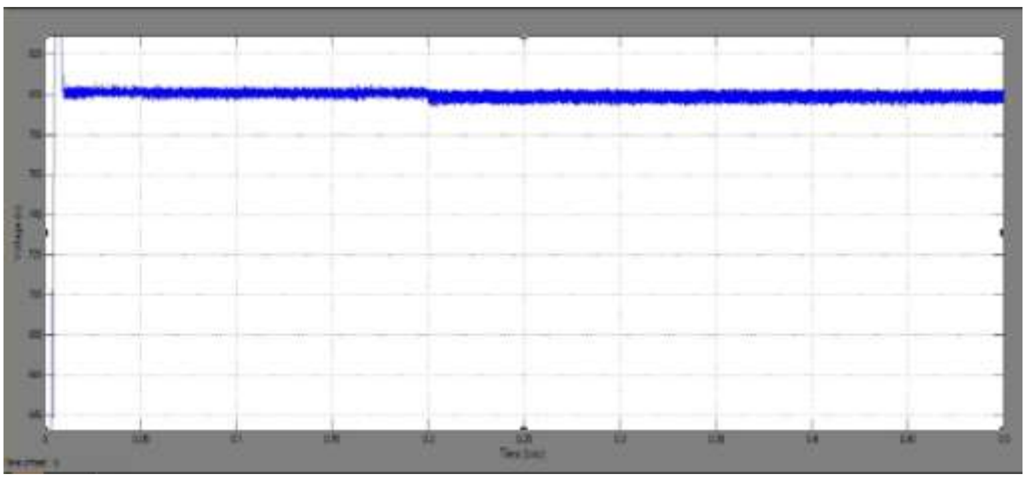

Fig 17: simulation results of dc voltage with hybrid fuzzy at dc sudden load

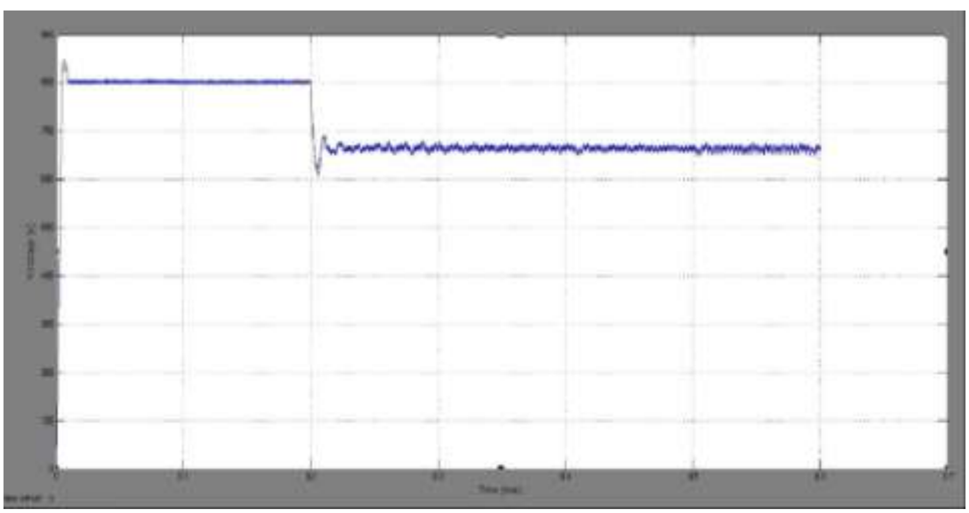

Fig 18: simulation results of dc voltage with fuzzy at dc sudden load

VII. CONCLUSION

The proposed work deals with the power control strategies of a fuzzy controlled grid connected hybrid PV/PEMFC/BATTERY and the output of dc was compared with hybrid fuzzy control. It has better output than fuzzy. It responds to the disturbances and settles down to steady state quickly and less peak overshoot. MATLAB/SIMULINK model results have good response.

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